1. **TECHNOLOGY NAME:**

Multispectral Imaging System

2. SPONSORSHIP:

2.1. IPDT Sponsor:

Donald Lencioni, MIT Lincoln Laboratory, 781-981-7996

2.2. Team Members:

David Hearn, MIT Lincoln Laboratory, 781-981-0918; Karl Blasius, Raytheon SBRS, 805-562-7592; Dexter Wang, SSG, 978-694-9991

3. OVERVIEW:

The two following sections provide the motivation for inclusion of this technology in the EO-1 mission, and give a brief description of the multispectral focal plane system. Also described there is the flight calibration system. The wide field-of-view optical system, which is an essential part of the Multispectral Imaging System, is treated elsewhere as a technology to be validated in its own right.

Section 6 below describes specific technical validation objectives, and the plans for attaining them. Though they are discussed separately, many of them will be pursued simultaneously, through integration and testing (I & T) before launch, on-orbit calibrations, and acquisition of multispectral earth scene data. Section 7 gives the scientific validation plan. Again, it is impossible to completely separate the scientific validation objectives from the technical ones, since some of them in practice rely on the same observational data.

4. INTRODUCTION:

Since 1972, the Landsat series of satellites have been producing seasonal multispectral images of the land area of the earth, which are used for studies such as land use patterns and global change research. The multispectral imaging instruments are called Landsat Thematic Mappers (TM’s). They include up to six spectral bands in the reflected-solar portion of the spectrum (0.4 to 2.4 μm). The basic spatial sampling interval for the multispectral bands is 30 meters on the ground. Later instruments in the series include a panchromatic (PAN) visible band, with finer spatial sampling, and a thermal (11-13 μm) band with coarser sampling. All TM instruments are designed to image a swath of 185 km on the ground, or 15° angular extent.

It is the responsibility of NASA to maintain and extend the TM coverage of the earth, with instruments designed to produce data which may be directly compared with earlier TM data. Landsat 5 is the most recent in the series to fly. Landsat 6 was lost in 1993, without achieving orbit.. MIT Lincoln Laboratory was asked to conduct a study in 1993, to recommend an interim replacement for Landsat 6. The instrument concept which emerged from that study was smaller, lighter, and lower in cost than the current Enhanced Thematic Mapper (ETM) designs of

Landsats 6 and 7. In return for dropping the thermal imaging band, it exceeded all other TM requirements, and could be produced on a tight schedule. The design concept was refined by the New Millennium Program Instrument Technology and Architecture team and was adopted for the EO-1 mission. Since then Landsat 7 was successfully launched on 15 April 1999.

The Advanced Land Imager aboard the EO-1 satellite is to incorporate a Multispectral and Panchromatic Imaging System, and a Radiometric Calibration System. The overall objective is to demonstrate the capability of these systems to produce calibrated, multispectral images of the land area of the earth, with performance equal or superior to that of the Landsat Thematic Mappers.

5. TECHNOLOGY DESCRIPTION:

The Multispectral Imaging System comprises a wide-field of view, all-reflective optical system, and a quasi-linear array of many detectors at its focal plane, operated in a pushbroom scanning mode. The detector array is composed of several sensor chip assemblies (SCA's), each of which includes multiple rows of detectors, operating in different spectral bands, and an assembly of bandpass filters for the various rows. In addition to the multispectral detectors, which are arranged to have a ground sampling distance (GSD) of 30 m, each SCA also includes an array of panchromatic (Pan) detectors for visible light, which have a 10 m GSD. The visible and near infrared (VNIR) detectors (for 0.4 to 1.0 µm wavelengths) are integrated into the read-out integrated circuit (ROIC) of the SCA, while a detector array for the short-wave infrared (SWIR) wavelengths (1.0 to 2.4 µm) is indium bump-bonded to the same ROIC, as a hybrid assembly. The entire focal plane assembly is cooled by a passive radiator. Resistive heaters and a control circuit maintain the FPA temperature at a steady 220K.

Although the optical system is designed to provide the full 15° field of view in the cross track direction which is required for an operational mission, the present instrument is furnished with only four SCA's, to cover 3° of that field. This is deemed sufficient for the purpose of this mission, which is technology validation. The optical system is described in another section of this document.

An essential complement to the Multispectral Imaging System is an in-flight calibration system. The goal for the ALI is to acheive 5% absolute radiometric accuracy, 2% band-to-band radiometric accuracy, and 1% [TBR] repeatability of measurements. The flight calibration hardware includes a solar calibration subsystem and internal flood lamps to stimulate the focal plane detector array. The solar calibrations are performed by inserting a diffuse reflector (of Spectralon) in front of the secondary mirror of the telescope, and pointing the telescope at the sun with its aperture cover closed. Within the aperture cover, a blocking slide is smoothly withdrawn from a set of entrance ports, to admit graduated amounts of the solar beam. Known amounts of sunight will then scatter from the diffuse reflector, some of which will illuminate the focal plane. The sizes of the entrance ports are carefully calculated to produce irradiances at the focal plane equivalent to those received from the earth, with albedos ranging from 1% to 90%, in several steps. Knowledge of the reflectance properties of the diffuse reflector and of the solar spectrum is then combined with the raw calibration data to derive the radiometric calibration of the instrument.

After every data collection event, detector readings are made with the aperture cover closed, to calibrate the zero-radiance offsets. The internal flood sources are also briefly turned on during this process. They provide a frequent, independent check of the solar calibration, which might drift over the life of the mission. Additional checks of the calibration are to be performed at longer intervals, by imaging the moon, and selected areas on the ground for which contemporaneous, independent measurements are available.

Table 1. Multispectral Arrays

Pixel pitch (across track)	39.6 µm
Pixel height (in track)	40 µm
Pixel format (Four modules, staggered and overlapped to ensure uninterrupted coverage)	1,250 (across track) × 1 (in track), within each spectral band. Odd and even pixels are in separate rows, separated by 80 µm in-track. SWIR bands 5’, 5 & 7, have redundant pixels, with the better one selected for readout.
Band spacing (in track)	800 µm
Readout rate (nominal)	226 frames/second

Table 2. Panchromatic (PAN) Array

Pixel pitch (average, across track)	13.2 µm
Pixel height (in track)	13.2 µm
Pixel format (Four modules, staggered and overlapped to ensure uninterrupted coverage)	3750 × 1 Odd and even pixels are in separate rows, separated by 80 µm in-track.
Readout rate (nominal)	678 frames/second

6. TECHNICAL VALIDATION OBJECTIVES:

6.1. Technical Validation Objective #1:

Verify the specified performance of the individual sensor chip assemblies:

6.1.1. *Required Data/Necessary Measurements:*

The responsivity and noise level of each pixel, as a function of wavelength and irradiance level, is required. A few hundred frames of data are sufficient to determine responsivity and white noise at each condition. Excess low-frequency noise (ELFN, or “1/f” noise) must be measured over a span of at least one minute, preferrably several minutes. Selected responsitivity and noise measurements must be repeated at various integration times. Detailed spectral response measurements, with enough spectral resolution to delineate the features of each filter, may be performed on a representative sample of pixels, distributed over the filter. Variations in the performance with temperature, over the range from 215 K to 225 K, must be measured. Spatial and band-to-band crosstalk measurements are needed, for a representative sample of pixels.

6.1.2. *Approach:*

The in-band responsivity and noise levels of each pixel, over levels from 0 to 100% of maximum irradiance, shall be measured at the module level by the focal plane vendor. The full set of measurements will be made at the nominal operating temperature of the focal plane. Selected measurements shall be repeated at 215 and 225 K. For these tests, a broad-band source having a known spectrum is needed to irradiate the SCA. The ELFN measurements may be done with data which are sparsely sampled in time. To perform spatial crosstalk measurements, an image of a line (or knife edge) will be projected onto the focal plane. Band-to-band crosstalk (and out-of-band response) is best measured by irradiating the module with a narrow wavelength range, obtained through a monochrometer.

6.1.3. *Anticipated Results:*

The responsivity vs. wavelength is expected to be very close to that obtained from the curves of filter transmission and detector quantum efficiency. The filter transmission curves are expected to resemble closely those of the ETM+ of Landsat 7, with the addition of several new bands. Some variation of transmission and/or center wavelength over the length of a filter may be found. Quantum efficiency curves are expected to resemble those obtained for similar detectors produced in the past by SBRC. The variation from pixel to pixel of the cutoff wavelength may be noticeable, but should not greatly affect the in-band response through the filters. Variations of responsivity and white noise of ±20% of the mean values may be found among the pixels. The variation of dark current with focal plane temperature will be very significant for the SWIR detectors, but much less so for the VNIR detectors. A few percent of the pixel set may have severely degraded performance, so as to classify them as “dead.” Non-linearity of radiometric response, at both high and low irradiances, is expected to be • 2%. The largest uncertainty at this time is the level of ELFN, and whether or not it will depend on irradiance level.

6.1.4. *Supporting I&T Data:*

The transmission vs. wavelength of each filter shall have been measured by the filter vendor, at several points along each filter. The quantum efficiency of the detectors vs. wavelength shall have been measured by the focal plane vendor. Characterization tests of individual read-out integrated circuits (ROIC's) and SWIR detector arrays will have been done prior to hybridization and assembly into the module.

6.1.5. *Rationale:*

The fundamental characteristics determining spectral response should not be affected when the individual components are placed into a sensor chip assembly, nor when the assembly is incorporated into a module. Provided that the piece parts perform according to their individual specifications, the SCA performance is most efficiently validated by combining data from tests performed at the integration levels where they are most easily done. Characteristics of filters should vary slowly, if at all, as a function of position along the filter, so it is not necessary to analyze the detailed spectral response at each pixel.

6.2. Technical Validation Objective #2:

Verify the system-level optical, spectral, radiometric, and pixel data transfer performance during instrument I & T:

6.2.1. *Required Data/Necessary Measurements:*

The optical performance validation requires measurements of the system modulation transfer function (MTF) at several points distributed over the field of view. Locations of the pixels within the field of view must also be measured. Responses of representative pixels to monochrometer scans are required to validate the system spectral performance. System radiometric performance shall be validated by measurements of the response of every pixel to known broad-band irradiances. Pixel data transfer validation requires the recording and reconstruction of images in a variety of patterns. Selected measurements must be repeated with the focal plane and telescope at maximum and minimum anticipated operating temperatures, to establish the effects of temperature variations. Selected measurements must also be repeated at various integration times.

6.2.2. *Approach:*

The instrument will be installed on a positioning fixture in the thermal vacuum chamber. The focal plane will operate at its nominal temperature, 220 K. For radiometric performance validation, an integrating sphere will be placed in front of the chamber window, so that the field of view of the MS/Pan array is filled with the uniform radiance of the sphere. That radiance will also be monitored with a well-calibrated spectroradiometer. Pixel data will be recorded at various radiance levels, from 0 to 100%. During this process, the internal flood lamps will be exercised, to establish their external radiance equivalence for each pixel. An imaging collimator, having a field of view of approximately 3°, will be substituted for the integrating sphere for MTF and imaging measurements. MTF measurements will be made by translating a knife edge mask slowly across the focus of the collimator. During end-to-end imaging tests, translating the test target on a computer-controlled linear stage will simulate the apparent motion of the earth. In order to achieve appropriate radiance levels with light sources of modest power, monochrometer scans may be done with a small integrating sphere at the focus of a collimator, rather than with the full-field integrating sphere used for radiometric calibrations.

The relative angular locations of pixel lines of sight will be measured by projecting reticle patterns into the instrument, and reconstructing the resulting images. Comparison of the reconstructed image of the reticle with the known angular relationships of its features will lead to a determination of the pixel lines of sight.

6.2.3. *Anticipated Results:*

The spectral response results should conform closely to predictions based on the measured characteristics of the mirrors, detectors, and filters. Radiometric responses and noise levels should be very similar to those obtained at the module level before system integration. The MTF characteristics should be dominated by the pixel size and integration time smearing, for most of the MS bands. Pixel size and integration time smearing should also be the major factor in the Pan MTF. The relative line-of-sight angles of the pixels are expected to be the same as those derived from separate measurements of telescope optical distortion and the sensor chip locations on the focal plane.

6.2.4. *Supporting I&T Data:*

Tests on the optical subsystem will include interferograms of wavefront distortions at various points around the field of view, and measurements of optical distortion across the whole field. Reflectance tests should also be made on witness samples from the mirror coating operations. The calibration system collimator and vacuum chamber window will also be characterized with interferograms and transmission measurements. Locations of the sensor chip assemblies on the focal plane will be measured to within ± 4 µm.

6.2.5. *Rationale:*

Integrated system tests are required primarily to verify that the system works as expected, under environmental conditions similar to those on orbit. The performance should be predictable from measurements made at the component and subsystem level. End-to-end system level calibrations not only serve as a check on those predictions, but should be more accurate, since fewer measurement uncertainties enter into the final result. Furthermore, the performance of the focal plane, as a complete system, will not be measured at its operational temperatures until these system-level tests.

6.3. Technical Validation Objective #3:

Demonstrate any performance changes once on orbit:

6.3.1. *Required Data/Necessary Measurements:*

To check for performance changes on orbit will require solar calibration, internal flood lamp, and lunar scan data, as well as normal earth-imaging data sets. Full sets of housekeeping data are required as well.

6.3.2. *Approach:*

Responsivities, dark readings, and noise levels of the detectors derived from the solar calibration process on orbit will be compared with those obtained during I & T. Readings of the flood sources will also be compared with the corresponding readings during I & T. Lunar scans will be used to check the optical resolution against that measured during I & T.

6.3.3. *Anticipated Results:*

The optical resolution performance is not expected to be measurably different on orbit than on the ground, except for possible spacecraft jitter effects. That jitter is presently anticipated to be insignificant. Radiometric performance should be as predicted from I & T results, so long as the temperatures of the telescope, focal plane, and electronics remain within the extreme limits measured during I & T. Temperature gradients in the instrument will probably differ from those during ground tests, but not enough to induce performance changes.

6.3.4. *Supporting I&T Data:*

Radiometric calibration data, and MTF measurements obtained during I & T are essential for this validation. Measurements of all temperature sensitivities will also be used.

6.3.5. *Rationale:*

The objective of the calibration process during I & T is to replicate the on-orbit environment as closely as feasible. The whole instrument is designed and tested to be robust enough to withstand the launch environment without changing. The instrument is also designed to be insensitive to its mean temperature, so long as the thermal gradients are within expected ranges.

6.4. Technical Validation Objective #4:

Confirm on-orbit optical, spectral, radiometric, and pixel data transfer performance of the multispectral sensor chip assemblies:

6.4.1. *Required Data/Necessary Measurements:*

Solar calibration data sets are required to confirm spectral and radiometric performance. Detector data recorded with the aperture cover closed, and flood lamps on and off, as well as housekeeping data, are an essential part of every data collection event. Lunar scans, or images of earth scenes which contain prominent high-contrast edges, are required to confirm the MTF performance. Multispectral images of earth scenes containing numerous ground control points are required, for validation and/or refinement of the pixel line-of-sight map. A number of earth scenes must be acquired contemporaneously with Landsat 7.

6.4.2. *Approach:*

Radiometric performance on orbit should be confirmed by the agreement (within expected uncertainties) between solar calibration and I & T radiometric calibration. Spatially homogeneous portions of earth scenes obtained on orbit will be compared with Landsat 7 images of the same scenes, to validate the estimated in-band radiances and band ratios. Lunar scans, or sharp linear features in earth images, will be used to estimate the MTF, which will then be compared with that obtained during I & T. Known locations of ground control points will be compared to apparent locations of those points in the reconstructed images to refine the pixel LOS map.

6.4.3. *Anticipated Results:*

No detectable change in spectral performance or MTF is anticipated. Radiometric performance should be entirely consistent with that obtained in the laboratory. Pixel data transfer performance will be identical to that obtained during I & T. Small incremental changes in the pixel LOS map may be indicated by differences between the true and apparent locations of ground control points. Since spectral characteristics are almost impossible to measure on orbit, spectral performance will be assumed to be unchanged, unless significant radiometric discrepancies are found, or comparison with multispectral Landsat images reveals unexpected band ratios. Absolute radiances may disagree with those from Landsat 7, but within overall measurement uncertainties.

6.4.4. *Supporting I&T Data:*

Spectral, radiometric, and MTF measurements during I & T will support this validation. Imaging tests from I & T will demonstrate pixel data transfer performance prior to launch. Pixel LOS measurements from I & T will form a baseline data set, possibly to be refined.

6.4.5. Rationale:

Full imaging operation of the instrument is the best, if not the only way to confirm the performance of the multispectral sensor chip assemblies on-orbit. Every available type of supporting data, including comparison Landsat images, will be used to validate the performance of the SCA's and the telescope optics. While MTF is primarily determined by the telescope, the SCA can alter it through the effects of optical and photoelectron crosstalk.

6.5. Technical Validation Objective #5:

Demonstrate the system's capability to gather Landsat-type images of 30 meter resolution over 10 Landsat-type spectral channels spanning the spectrum from 0.4 to 2.4 micrometers across a 36 kilometer contiguous swath from a circular orbit of 705 km altitude:

6.5.1. Required Data/Necessary Measurements:

A variety of earth scenes need to be acquired by the multispectral imaging system, including different types of terrain and ground cover, at various latitudes. The precise spacecraft ephemeris is required for the planning of each data collection event. Solar calibrations should be performed near the time of the earth observations. Ideally, scenes previously recorded by a Landsat Thematic Mapper should be observed.

6.5.2. *Approach:*

Acquisitions of multispectral images of earth scenes, over a variety of latitudes and range of seasons, will be planned and carried out as a part of the normal mission operations. Solar and internal calibrations will also be part of the mission operations. Data will be processed through the calibration pipeline, then geometrically reconstructed as multispectral images, for comparison with similar Landsat multispectral images.

6.5.3. *Anticipated Results:*

The fully-reconstructed images should look very similar to corresponding Landsat multispectral images, but with several additional bands. The signal to noise ratio should be several times higher than for Landsat images.

6.5.4. Supporting I&T Data:

Spectral measurement scans and pixel LOS determinations during I & T are essential for the correct processing of the on-orbit data. Radiometric calibrations from I & T will support the on-orbit calibration pipeline. Laboratory MTF measurements will used to check the spatial resolutions achieved on orbit.

6.5.5. *Rationale:*

This validation is the overall goal of the mission, for this technology. The design of the instrument, and the integration and test plan, all support this goal.

6.6. Technical Validation Objective #6:

Conduct monthly on-orbit assessments of the effects of the space environment, and in particular, any changes in calibration during the first year on orbit:

6.6.1. Required Data/Necessary Measurements:

To check for radiometric calibration changes on orbit will require periodic solar calibration data sets. Detector data recorded with the aperture cover closed, and flood lamps on and off, as well as housekeeping data, are an essential part of every data set. Lunar scans are needed to check for MTF changes, and to assess long-term drifts in the radiometric calibration.

6.6.2. *Approach:*

Solar calibrations will be conducted frequently when on-orbit operation of the instrument begins, then at longer intervals as a data base of calibrations accumulates. As a part of the calibration pipeline processing, each result will be compared with that from the internal sources, with the I & T calibration data, and the preceding solar calibration data. Long-term trends will be derived, and any sudden changes flagged for attention. Images of the earth and lunar scans will be inspected for any artifacts or signs of deterioration in resolution.

6.6.3. Anticipated Results:

The initial solar calibration results will probably disagree with the I&T radiometric calibration data by a few percent. The subsequent calibrations should agree much more closely with each other, after taking into account any temperature dependencies, which shall have been established during I & T. The internal sources will gradually lose intensity, as a function of their total operating time. Lunar scans provide an ultimate check on long-term drift of the radiometric calibration, although extensive image processing may be required to analyse those data, and the fundamental radiance maps are not yet available. Lunar scans do provide an immediate check on the spatial resolution of the system.

6.6.4. *Supporting I&T Data:*

Radiometric calibrations and MTF measurements obtained during I & T will form a bassis of comparison for on-orbit performance assessments.

6.6.5. *Rationale:*

Changes caused by the space environment may occur at many different rates. Rapid changes must be detected by frequent measurements early in the flight. Slower changes may be detected by measurements at increasingly longer intervals. Measurements should be started at the earliest opportunity, in order to separate launch-induced changes from those attributable to the to the space environment.

6.7. Technical Validation Objective #7:

Verify the specified performance of the calibration system during instrument I&T:

6.7.1. *Required Data/Necessary Measurements:*

The on-board calibration subsystem must be exercised during instrument I & T, to verify correct results from the solar calibrator, and to calibrate the internal flood lamps as transfer standard sources. Measurements of the spectral reflectance and bidirectional reflectance distribution function (BRDF) of the diffuser are essential.

6.7.2. *Approach:*

A test of the on-board solar calibration system will be done by directing a small-divergence light beam at the instrument with its aperture cover closed, and the diffuser in place. The calibration aperture slide will then be cycled. A large diffusely-reflecting panel will then be inserted into the same light beam, and the instrument will be operated in the usual mode to form an image of the panel. The apparent reflectance of that panel, derived from the pixel readings in the direct and reflected observations, will then be compared to the independently-measured reflectance of the panel.

During the radiometric calibration process, the internal flood lamps will be exercised, to establish their external radiance equivalence for each pixel.

6.7.3. *Anticipated Results:*

The test of the solar calibrator should confirm the accuracy of the process to 5% or better. An array of pixel responses to the internal flood sources will be obtained, which will be re-expressed in terms of equivalent input radiances.

6.7.4. Supporting I&T Data:

Measurements of the BRDF of the diffusely-reflecting panel, and the angle of incidence at which it is used in this test, are required. The intensity of the beam shall also be monitored continuously during the test. The radiometric calibrations of the pixels are needed, in order to express the response to the internal flood sources in terms of equivalent input radiances.

6.7.5. Rationale:

The solar calibrator test will validate the on-board calibration system, without the requiring the use of a beam having the full spectral irradiance of sunlight.

6.8. Technical Validation Objective #8:

Verify the operation of the calibration system, once on orbit:

6.8.1. *Required Data/Necessary Measurements:*

To verify the operation of the calibration system on orbit will require solar calibration, internal flood lamp, and lunar scan data, as well as images of earth scenes containing large, well-characterized uniform areas (such as White Sands) . Full sets of housekeeping data are required as well.

6.8.2. Approach:

The solar calibration mode will be exercised soon after the instrument is activated on orbit. As for all other pixel data collection operations, readings will be taken with the aperture cover closed, and flood lamps on and off. The solar calibration data will be processed through the calibration pipeline, and the resulting pixel responsivity calibrations will be compared with those obtained during laboratory I&T, and those obtained from the flood source readings. As soon as feasible, a lunar scan will also be performed, and the apparent radiances of the lunar surface, determined via the solar calibration, will be compared with published values. Images of areas such as White Sands, taken when independent, calibrated measurements are performed, will serve as another validation check.

6.8.3. Anticipated Results:

The results of the solar calibration should agree, to within a few percent, with the results of the radiometric calibrations performed during I & T. The solar calibration should also agree with that derived from flood source data to better than 10%. Vicarious calibrations, from contemporaneous observations of ground targets, should also be consistent, to within the errors of the various measurements. Lunar radiance data may not be available for several years, but it may provide the best post-facto calibration, since it is unaffected by the changing atmosphere. A sufficiently large number of cross-comparisons will be available that systematic flaws in any single calibration path should be readily apparent.

6.8.4. Supporting I&T Data:

Laboratory measurement of the pixel responsivities, performed with NIST-traceable reference standards, will be the basis for evaluating the operation of the on-board calibration system. These data will be buttressed by characterization data taken during subsystem acceptance tests by the vendors. The spectral reflectance and bidirectional reflectance distribution function (BRDF) of the diffuser is also an essential measurement. The reflectance of the secondary mirror must also be known, because it is not in the optical train during solar calibration.

6.8.5. Rationale:

Every precaution is being taken to protect the diffuser surface from degradation both before and after launch. The Spectralon material has a very high reflectance across the spectrum of interest, and a very nearly Lambertian BRDF. Provided that the mechanisms operate as they are designed to do, and that stray light within the telescope is effectively baffled from reaching the focal plane, the solar calibration system should give a radiometric calibration limited basically by the accuracy of the spectral reflectance measurement of the diffuser. Other calibration paths will give different answers, with various degrees of accuracy. Most of them have more potential sources of error than the solar calibration. Although errors in the spectral irradiance assumed for the sun will directly affect the radiometric calibration of the instrument, if that same spectral irradiance is used to derive surface reflectances, the resulting error cancels out. The surface reflectances are, in effect, being referred to that of the Spectralon diffuser.

7. SCIENTIFIC VALIDATION OBJECTIVES:

7.1. Scientific Validation Objective #1:

Perform 200 paired-scene comparisons with Landsat 7 (ETM+), comparing the spectral reflectance of known land surface features:

7.1.1. *Required Data/Necessary Measurements:*

7.1.2. *Approach:*

7.1.3. *Anticipated Results:*

7.1.4. *Supporting I&T Data:*

7.1.5. *Rationale:*

7.2. Scientific Validation Objective #2:

Gather multispectral terrain images that capture the natural geographic, seasonal, and climatic variations encompassing one entire growing season in the northern hemisphere:

7.2.1. *Required Data/Necessary Measurements:*

7.2.2. *Approach:*

7.2.3. *Anticipated Results:*

7.2.4. *Supporting I&T Data:*

7.2.5. *Rationale:*

7.3. Scientific Validation Objective #3:

Demonstrate the stability of the multispectral capability by scheduling the collection of paired-scene comparisons to span the first year on orbit:

7.3.1. *Required Data/Necessary Measurements:*

7.3.2. *Approach:*

7.3.3. *Anticipated Results:*

7.3.4. *Supporting I&T Data:*

7.3.5. *Rationale:*

7.4. Scientific Validation Objective #4:

Periodically demonstrate and assess the efficacy of the different calibration modes over the first year on orbit:

7.4.1. *Required Data/Necessary Measurements:*

7.4.2. *Approach:*

7.4.3. *Anticipated Results:*

7.4.4. *Supporting I&T Data:*

7.4.5. *Rationale:*

8. SCHEDULE:

9. REQUIRED MANPOWER:

10. REQUIRED FACILITIES:

11. SIGNATURES:

11.1. IPDT Provider:

11.2. Project Scientist:

11.3. Project Manager:

11.4. GSFC Program Manager:

11.5. NMP Program Manager: